

ADVANCES IN SUGARBEET PRODUCTION: PRINCIPLES AND PRACTICES



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Irrigation and Water Management

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THE SUGARBEET PLANT is adapted to a wide range in climate. It is a major crop in irrigated areas because of its tolerance to salinity, hardness, and its productivity which makes it a good cash crop under various growing seasons and soils. The major areas of irrigated sugarbeets are in California, Colorado, Idaho, Nebraska, Washington, and Wyoming. The major non-irrigated sugarbeet areas are in the Red River Valley of Minnesota and North Dakota and in Michigan (37).

The objectives of this chapter are to summarize (1) measured evapotranspiration from the sugarbeet crop and to relate these values to meteorological conditions and degree of crop cover at various stages of plant growth, (2) the effects of various soil moisture levels on root yield and sugar production, and (3) the major characteristics of various irrigation methods and to recommend practical procedures for irrigation water management to assure near-optimum production of sugar.

Irrigation provides a favorable soil environment for the germination of seeds, emergence of seedlings, and development of the root system, and maintains favorable moisture levels and salt concentrations in the soil solution so as not to restrict significantly the photosynthetic process (15, 20). The amount of water retained within the tissue of the beet tops and the

beet roots is only about 1 percent of the total evaporated from a field during the growing season. Therefore, irrigation replenishes water that has been transpired by the plants or evaporated from the soil surface. However, since water evaporating from the soil surface is salt free and plants selectively absorb dissolved salts, sustained crop production also requires the maintenance of a favorable salt concentration in the soil. The only practical means of controlling the salt concentration is to allow a fraction of the water applied to the soil to pass through the root zone (leaching). The fraction of the water applied that is essential (leaching requirement) to control salts is a beneficial and necessary use of water (14).

Managing the soil moisture reservoir can be a relatively complicated procedure if the basic principles involved are not understood. The irrigator cannot see when the reservoir is full or nearly empty. In addition, the reservoir is leaky. If the root zone is refilled at each irrigation, some leakage or waste occurs for several days following each irrigation. However, if leaching is required, some deep percolation is essential.

Management of the reservoir can be relatively simply if a few basic principles are understood. The quantity of water evaporated from the soil and transpired by the plants is largely determined by the meteorological conditions and the degree of plant cover during the cropping season. Most sugarbeet evapotranspiration data include the sum of evaporation and transpiration from planting to harvest. There may be additional evaporation losses before planting in the spring and after harvest in the fall which must be considered when accounting for the annual water requirement.

DEFINITIONS

The following definitions explain the terminology used in this chapter. *Transpiration* is the loss of water in the form of vapor from plants. All aerial parts of plants may lose some water by transpiration, but most of the water is lost through the stomates.

Evapotranspiration is the sum of water lost by transpiration and evaporation from the soil or from exterior portions of the plants.

Consumptive use is essentially identical to evapotranspiration. It differs by the inclusion of water retained in plant tissues. For most agricultural plants, the amount of water retained by plants is insignificant when compared to the amount evaporated (15).

Deep percolation is the amount of water that passes beyond the root zone of the crop.

Leaching requirement is the relative portion of the irrigation water applied that must pass through the root zone in order to maintain a favorable salt concentration in the soil solution.

Effective rainfall is the amount of rainfall that is used in evapotranspiration and leaching.

Irrigation water requirement is the total amount of water required to

maintain a favorable soil moisture and salt concentration in the root zone when taking into account the various unavoidable losses.

FACTORS INFLUENCING EVAPOTRANSPIRATION

Evapotranspiration is affected by many factors. Man can influence or control some of these; others he has no control over, such as climate. Climatic factors include precipitation, solar radiation, temperature, humidity, wind movement, and length of growing season. Man can influence or control such factors as water supply, water quality, date of planting, crop varieties, soil fertility, plant spacing, water management, cultivation, and chemical sprays.

All these factors may influence plant growth and, thereby, evapotranspiration. Thus, evapotranspiration may vary from farm to farm, season to season, and day to day. When plants are young, the amount of water used is small. The amount used increases with plant growth and reaches a peak during some part of the growth period. Nevertheless, for optimum production at a specific location, the sugarbeet crop requires a fairly definite amount of water during the growing season.

The magnitude of daily evapotranspiration is controlled primarily by meteorological conditions when a green crop has sufficient leaf area and soil moisture so as not to limit evapotranspiration. In contrast, deep percolation is influenced by precipitation, soil characteristics, the amount of water applied at each irrigation, the frequency of irrigations, and the available soil moisture at the time of irrigation. Evapotranspiration is predictable mainly because it is limited at any time by the heat energy available for evaporation. As a result, evapotranspiration for a given crop will be similar in areas of similar climate and growing seasons. In contrast, deep percolation and other losses may vary widely, depending on the irrigation practices and the management of the system.

DETERMINING EVAPOTRANSPIRATION

The commonest method of determining E_t rates under field conditions, which has been used over 70 years, is gravimetric soil sampling 2 to 3 days after an irrigation, followed by another sampling in 5 to 20 days, or just before the next irrigation. More recently, the neutron soil moisture probe has been used. From the change in soil moisture and the rainfall received during the interval, the average E_t rate is calculated as follows:

$$E_t = \frac{W_1 - \sum_{i=1}^n \Delta \theta AS + R_n - W_n}{\Delta t} \quad (8.1)$$

in which W_1 = the total water used in evapotranspiration, S = the distance from the soil surface, S_r = the depth of the effective root zone, $\Delta \theta$ = the volumetric change in soil moisture (a negative sign indicating a decrease), R_n = effective rainfall, Δt = the time interval between sampling dates (usually days), E_t = the average evapotranspiration rate, and W_n = the water drained from the 0 to S_r depth. Drainage from the effective root zone or upward movement into the effective root zone is the major unknown in Equation 8.1 and is generally assumed to be zero. Drainage may be as large as E_t in the spring when E_t rates are low and the entire profile is wet. During these periods, the first sample after an irrigation should be taken at least 5 to 7 days after an irrigation.

Lysimeters are also used for determining evapotranspiration rates. These consist of a large volume of soil contained within a tank that is weighed by a mechanical, a combination mechanical and electrical, or a hydraulic weighing system. When properly installed, operated, and instrumented, lysimeters provide the most accurate measurement of evapotranspiration. Most of the data reported in this chapter were determined by soil-sampling techniques.

ESTIMATING EVAPOTRANSPIRATION

Daily evapotranspiration may be estimated using one of many rational and empirical equations. Most methods attempt to separate meteorological factors from soil-crop factors. One such technique is:

$$E_t = K_e E_p \quad (8.2)$$

in which K_e is a dimensionless crop coefficient relating the rate of evapotranspiration for a crop like sugarbeets to potential evapotranspiration (or the evapotranspiration for a reference crop such as well-watered grass or alfalfa, with at least 12 to 18 inches of growth). The crop coefficient is a parameter determined primarily by the wetness of the soil surface and the leaf area for a crop like sugarbeets. Potential evapotranspiration (E_p) is primarily determined by the magnitude of solar energy absorbed by the crop surface, the vapor pressure deficit of the atmosphere, windspeed, and the resistance to the passage of water vapor through the stomata.

The total amount of water required for the growing season is generally determined by summing the daily, weekly, or monthly estimates:

$$W = \sum_{i=1}^n (K_e E_p)_i \quad (8.3)$$

where i is the number of the time increment involved.

GROWTH STAGES AND CHARACTERISTICS

Growth stages and characteristics of sugarbeets can best be illustrated by typical curves representing the rate of top and root growth when beets are either spring planted or fall planted. Full cover of sugarbeet leaves is achieved slowly because of the small size of the juvenile leaves and because only 3 to 4 new leaves are initiated each week (24, 27). A leaf area index of 3 to 5, which can be considered as full cover, may not be attained until 60 to 90 days after planting (leaf area index = area of leaves, one side only, per unit of land surface). The leaf area index may go as high as 6 to 12 (28). In northern climates 100 to 120 days may be required to attain full cover because of low air and soil temperatures in the spring.

SPRING-PLANTED BEETS

The relative cumulative top growth and the cumulative root growth for spring-planted sugarbeets at Twin Falls, Idaho, is illustrated in Figure 8.1. These data dramatically illustrate the slow top growth development when beets are first planted, especially in northern climates where soil and

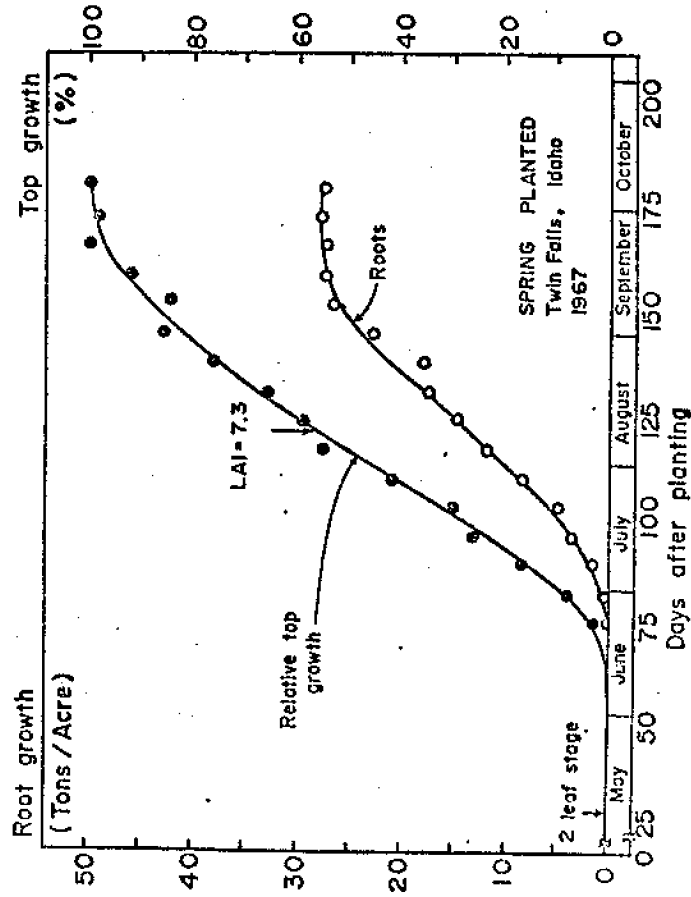


Fig. 8.1. Relative top growth and root growth for spring-planted beets at Twin Falls, Idaho. (After Carter et al., 2.)

air temperatures are low in the spring. In this example, the sugarbeet plants were at a two-leaf stage on May 8. Rapid top growth did not begin until the latter part of June. Full effective cover was attained near the latter part of July. A single leaf area index measurement of 7.3 was made on August 7. This value is generally greater than normally expected at this time of year (normally about 4).

Rapid root growth did not begin until July. The maximum growth rate occurred from the latter part of July to about September 1. During this period, root growth averaged about 3 tons per week. Most of the root growth occurred by mid-September.

Based on the leaf area attained between July 20 and August 1, evapotranspiration from sugarbeets would be essentially equal to the potential evapotranspiration rate from about July 25 until a severe frost. A frost may not kill the entire tops back, but research data indicate that a frost severely affects the rate of transpiration during the next few days.

FALL-PLANTED BEETS

Similar curves are presented for fall-planted beets at Phoenix, Arizona, in Figure 8.2. Data were not available on the top growth immediately

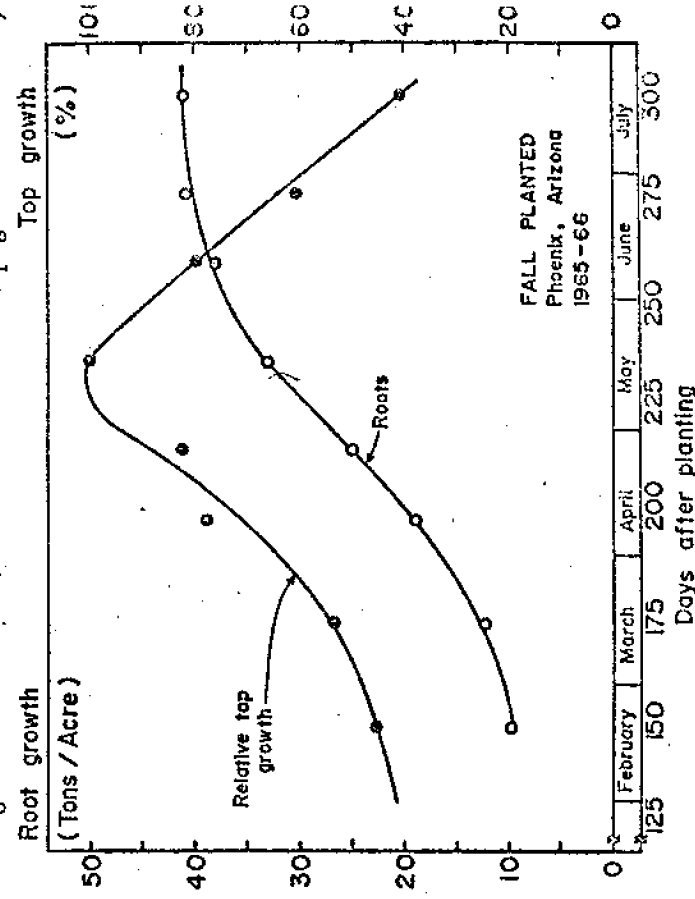


Fig. 8.2. Relative top growth and root growth for fall-planted beets at Phoenix, Arizona. (After Erie and French, 5.)

following planting on September 22. However, because of the warm soil, top growth increased rapidly until about January 20, when it began to decrease because of the low minimum temperatures (near 32° F.). Top growth rapidly resumed early in March, reaching a maximum in mid-May. Mean maximum temperatures near mid-May ranged from 90° to 95° F. Following mid-May, maximum temperatures ranged from 98° to 110° F. Root growth increased in March and reached a maximum in April and May. The maximum rate during April and early May in this example was 2.6 tons per week. Root weight reached a maximum by the latter part of June. Similar decreases in top growth occur in the lower San Joaquin Valley in July and August when beets are planted early in January (8).

EVAPOTRANSPIRATION

Numerous studies on the rate of evapotranspiration or consumptive use have been conducted in western United States and in other countries. Sufficient data are now available so that if the effects of degree of crop cover, surface soil moisture, and available soil moisture are separated from meteorological effects (potential evapotranspiration), one can estimate the rate of evapotranspiration for practical purposes on sugarbeet fields in any climatic regime. Similarly, one can also estimate the total evapotranspiration for the season. Typical data are presented in this section to illustrate rates of evapotranspiration for spring- and fall-planted sugarbeets grown under medium soil moisture conditions in widely varying climates. The similarity of crop coefficients for spring-planted sugarbeets in two different climatic zones and fall-planted sugarbeets is presented. These data substantiate the previous statement that if meteorological and soils data are available, evapotranspiration rates can be estimated for practical purposes of management or estimating water requirements. Such estimates are sufficiently reliable to enable scheduling irrigations using soil-crop-meteorological data (17, 19, 21).

Evapotranspiration rates vary with meteorological conditions, which are influenced by latitude, elevation, cloud cover, humidity, and windspeed when sufficient leaf area has been attained and soil moisture is not limiting. The rate of evapotranspiration for sugarbeets increases as leaf area increases until the evapotranspiration rate is approximately equal to the potential rate existing in that area under given climatic conditions. The data in Figures 8.3 to 8.10 illustrate these characteristics.

SPRING-PLANTED BEETS

Evapotranspiration rates for spring-planted sugarbeets grown in an intermountain area (Twin Falls) at an elevation of about 4,000 feet above sea level are presented in Figure 8.3. In this area, beets are planted early in April and attain an effective full cover about August 1. These data were

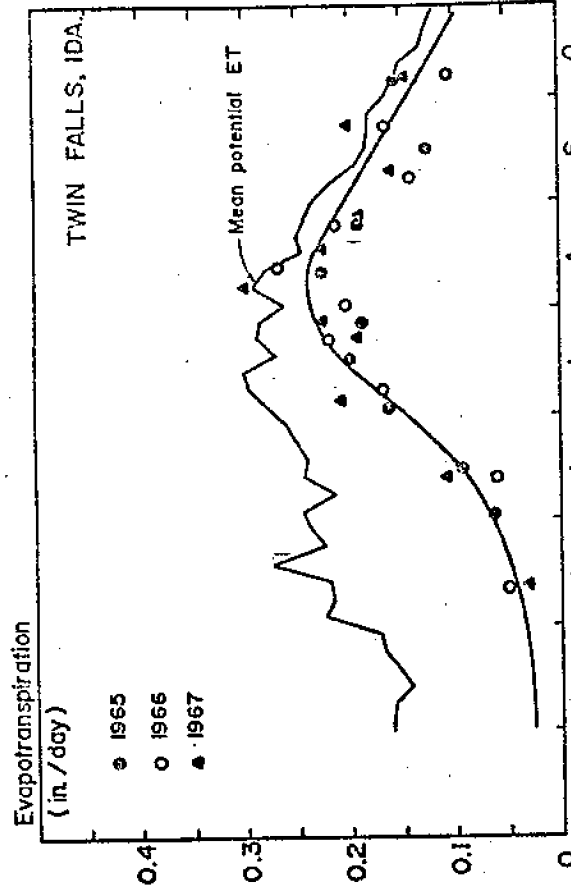


FIG. 8.3. Measured evapotranspiration and estimated mean potential ET during three growing seasons.

obtained in an irrigation experiment using a neutron soil moisture probe. Evapotranspiration rates early in May were only about 15 to 20 percent of potential evapotranspiration during this period, primarily because the soil was essentially bare (very limited leaf area). Although the evaporative demand increased slightly from the first part of June until mid-July, the rate of evapotranspiration increased more rapidly because the leaf area increased during this period. The rate of evapotranspiration was nearly equal to the potential evapotranspiration rate after the first of August. However, by this time the potential rate was decreasing as solar radiation and air temperatures decreased.

Similar data for the Northern Plains area are presented in Figure 8.4. In general, the same characteristics are prevalent in that area as at Twin Falls. Many of these data were obtained from old experiments conducted at Scottsbluff, Nebraska, in the early 1930s. These values may not represent the upper limit of evapotranspiration rates for sugarbeets under high soil moisture levels because the interval between irrigations may have been longer than desired for optimum soil moisture conditions. However, the curve as plotted in Figure 8.4 represents primarily the higher values and should be fairly representative of mean evapotranspiration rates expected in that area. Only a few points are presented for Newell, South Dakota. They are very similar but one would expect the rate for South Dakota to decrease more rapidly in the fall than at Scottsbluff.

These data were obtained by soil-sampling procedures. Scottsbluff is

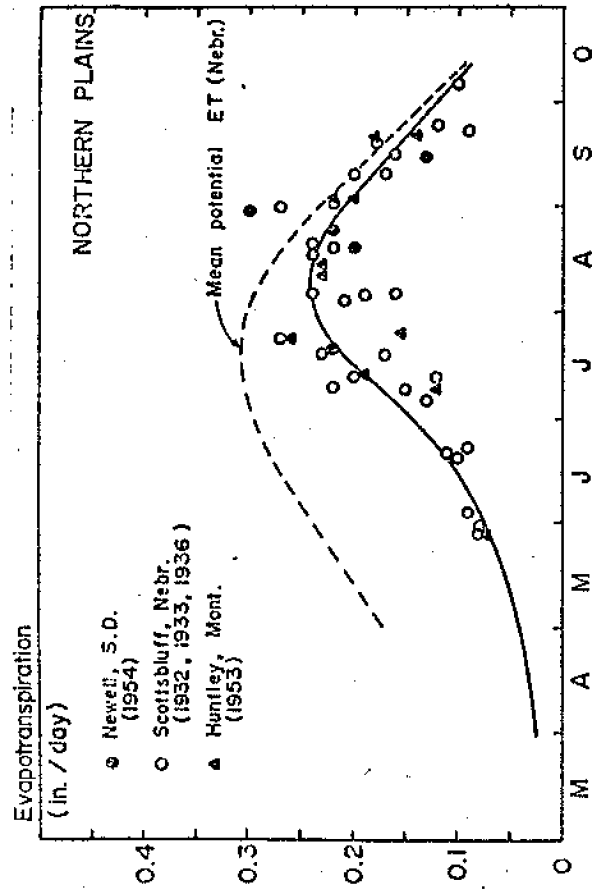


FIG. 8.4. Measured evapotranspiration at Newell, South Dakota (unpublished data, Baird and Bonnenman), at Scottsbluff, Nebraska (unpublished data tabulated by O. W. Howe), and at Huntley, Montana (Larson and Johnston, 22).

located at a latitude of 41° and $52'$ north and is about 4,000 feet above sea level. Newell is located 44° and $44'$ north and is about 2,900 feet above sea level. Huntley, Montana, is located 45° and $55'$ north and is about 3,300 feet above sea level.

Data for the Columbia Basin are presented in Figure 8.5. In this area, sugarbeets are planted early in March and attain an effective full cover about July 20. The elevation in the Prosser, Washington, area is approximately 840 feet. At these lower elevations, summer temperatures are higher even though the latitude is 46° and $15'$ north. Consequently, with the clearer skies and similar summer clear day radiation values, peak evapotranspiration rates are higher than at Twin Falls and Scottsbluff. The earlier data (1940, 1941, and 1949) were collected by H. G. Nickle and summarized by S. J. Mech (25). Data collected in the mid-50s were obtained by Middleton et al. (26). In general, those values represent optimum soil moisture conditions and generally are somewhat higher than the values obtained by Mech. The data collected by Nickle and Mech were on medium soil moisture levels where the yields were essentially the same as those obtained on a higher soil moisture level. However, data from the high soil moisture level indicate that some deep percolation may have occurred during the sampling interval. Again, the trend is very similar to that presented for Twin Falls and Scottsbluff. Evapotranspiration rates are less than the

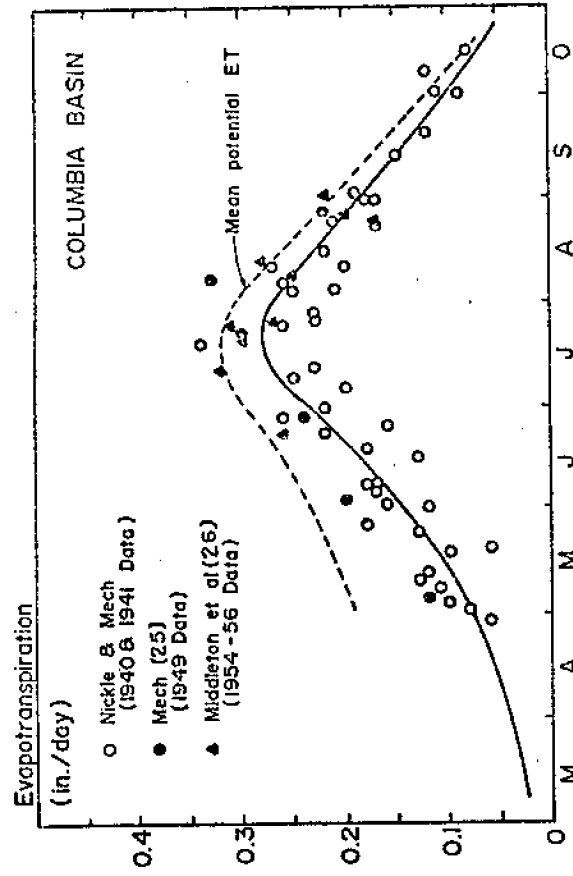


FIG. 8.5. Evapotranspiration and estimated mean potential ET for the Columbia Basin.

potential early in the year and approach the potential values, in this case, near mid-July. The decrease after July occurs primarily because of a decrease in potential evapotranspiration.

Similar data for the Southern Plains are presented in Figure 8.6 in which two years of evapotranspiration data determined at Bushland, Texas, using a neutron probe, are presented, along with the mean potential evapotranspiration for the two years involved. Evapotranspiration rates again show a similar trend in that they are significantly less than the potential in April and May, approach the potential early in June, and are about 90 percent of the potential value until approaching harvest in October. The values near the end of the season apparently represent the effect of decreasing soil moisture before harvest.

Recent studies of evapotranspiration from sugarbeets, using accurate weighing lysimeters at Davis, California, confirm these typical patterns. Evapotranspiration rates for beets planted March 25 were very similar to those obtained at Bushland (30).

If the ratio of evapotranspiration to potential evapotranspiration is calculated at various stages of growth for spring-planted sugarbeets in the Twin Falls area, a value referred to as a crop coefficient is obtained (15). Crop coefficients for Twin Falls are presented in Figure 8.7. When presenting the data in this manner, it is apparent that the rate of evapotranspiration ranges from 10 to 15 percent of the potential shortly after plant-

ing, which represents largely evaporation from the soil surface, and it increases to about 90 percent of the potential by August 10. Some of the scatter of data can be attributed to the measurement techniques involved. Similar but more accurate crop curves relating evapotranspiration from sugarcrops to evapotranspiration from grass are presented by Pruitt et al. (30).

Crop coefficients for Bushland are shown in Figure 8.8. In this case, the smooth line plotted is identical to the line plotted for Twin Falls, but with the horizontal axis shifted forward about 40 days. The two data points near the end of the season reflect the reduced evapotranspiration that takes place as soil moisture is allowed to decrease. In general, crop coefficients indicate that spring-planted sugarcrops in the western states require 3 to 4 months to attain full effective cover. Crop coefficients were not calculated for the Columbia Basin area, but Middleton et al. (26) presented ratios of evapotranspiration to pan evaporation, which would be very similar to the estimate of potential evaporation used in Figures 8.3 and 8.6. The average ratio of evapotranspiration to pan evaporation after full cover was attained was approximately 0.9, indicating that crop coefficients calculated for the Columbia Basin would probably be very similar to those presented in Figures 8.7 and 8.8 except the planting date and date of attaining full effective cover would need to be shifted accordingly.

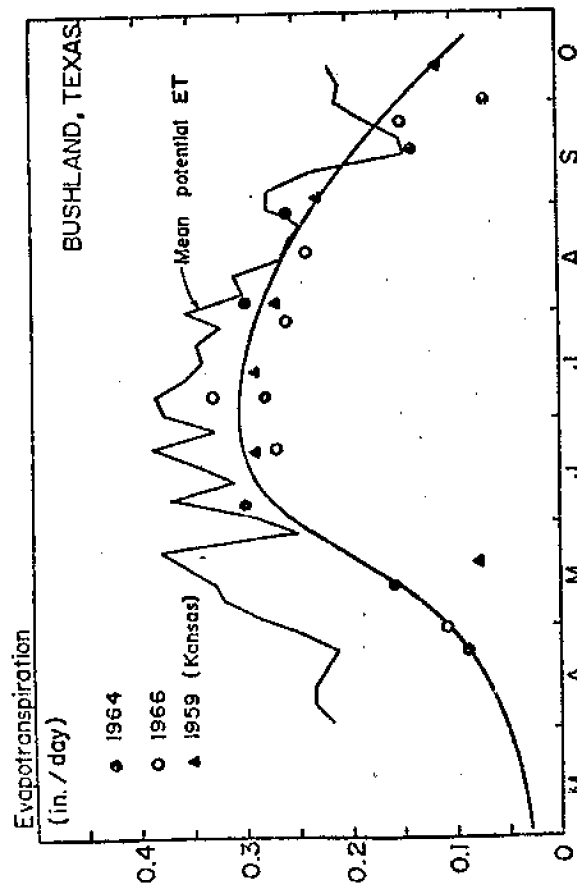


FIG. 8.6. Measured evapotranspiration and estimated mean potential ET for two years at Bushland, Texas (adapted from Schneider and Mathers, 35), and measured evapotranspiration for Garden City, Kansas (Herron et al., 15).

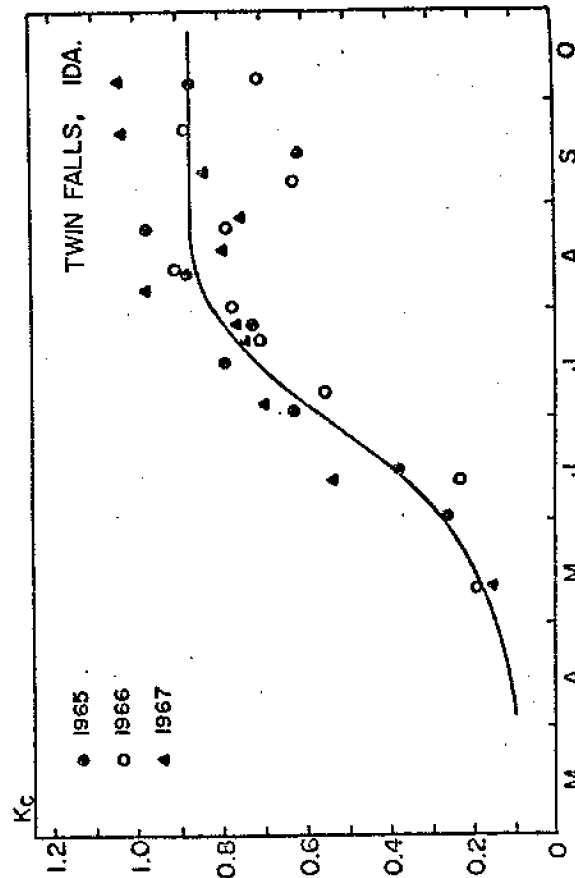


FIG. 8.7. Crop coefficient (E_c/E_p) for spring-planted sugarcrops at Twin Falls, Idaho.

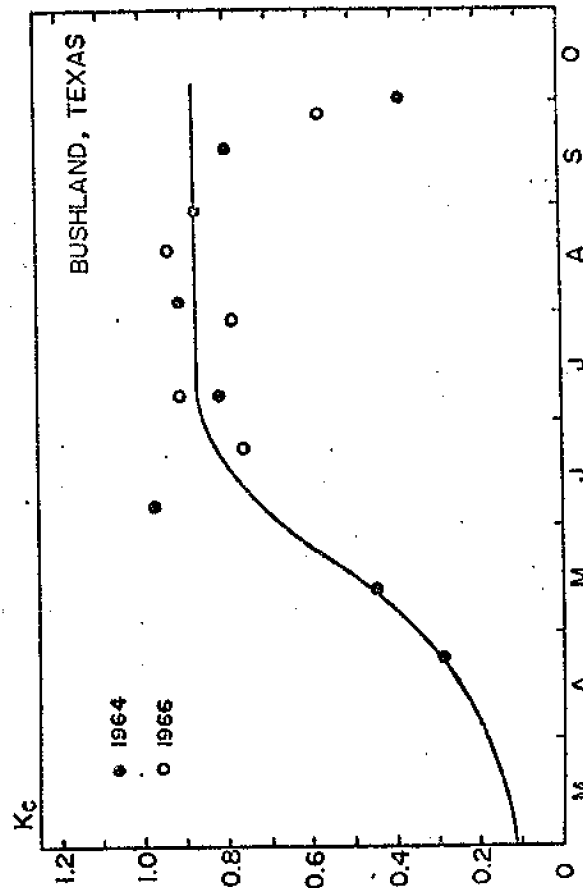


FIG. 8.8. Crop coefficients (E_c/E_p) for spring-planted sugarcrops at Bushland, Texas.

FALL-PLANTED BEETS

Evapotranspiration data for fall-planted sugarbeets near Phoenix are presented in Figure 8.9. These data were collected by L. J. Erié, using soil-sampling techniques. Phoenix is located at about 33° and 20' north latitude at an elevation of about 1,100 feet above sea level. The beets in the Phoenix area are planted early in October. They attain effective full cover by January, but the leaves begin to disintegrate and the plants defoliate from mid-January through February, due to low temperatures. During the study period, the minimums were near 32° or lower. New growth begins early in March and the evapotranspiration rate rapidly increases as leaf area increases; the potential evapotranspiration increases with increasing solar radiation and air temperature in the spring. Observed evapotranspiration rates again are approximately 90 percent of the potential after the full cover is attained. Because of high temperatures (greater than 100° F) beginning in May, the leaves begin to defoliate and by the latter part of June and July the observed rate of evapotranspiration is greatly decreased relative to the evaporative demand.

Crop coefficients for the Phoenix area are shown in Figure 8.10. Although the horizontal scale is different, the rate of increase in the crop coefficient from near the first of October through mid-January is essentially identical to that for the spring-planted sugarbeets. The decrease in the crop coefficients beginning in mid-January through February clearly illus-

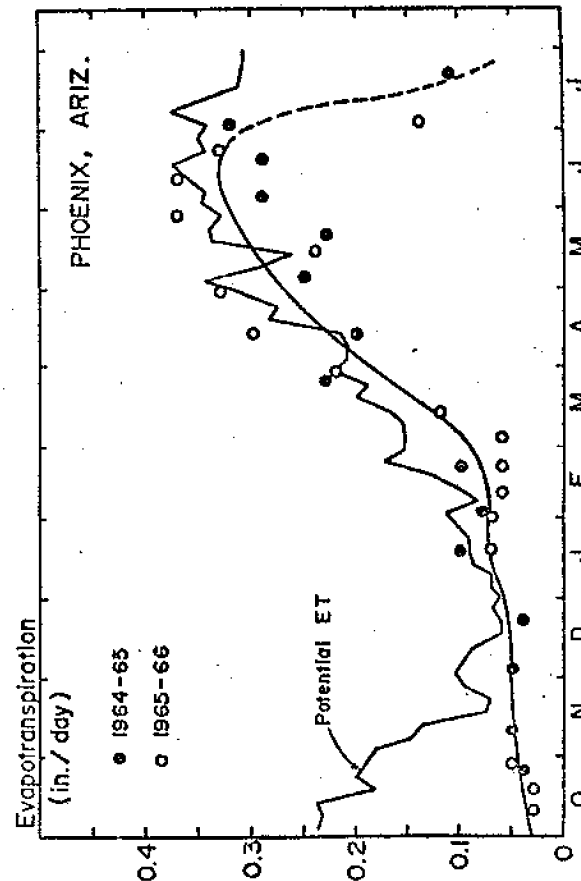


FIG. 8.9. Measured evapotranspiration and estimated mean potential E_t for the two-year period.

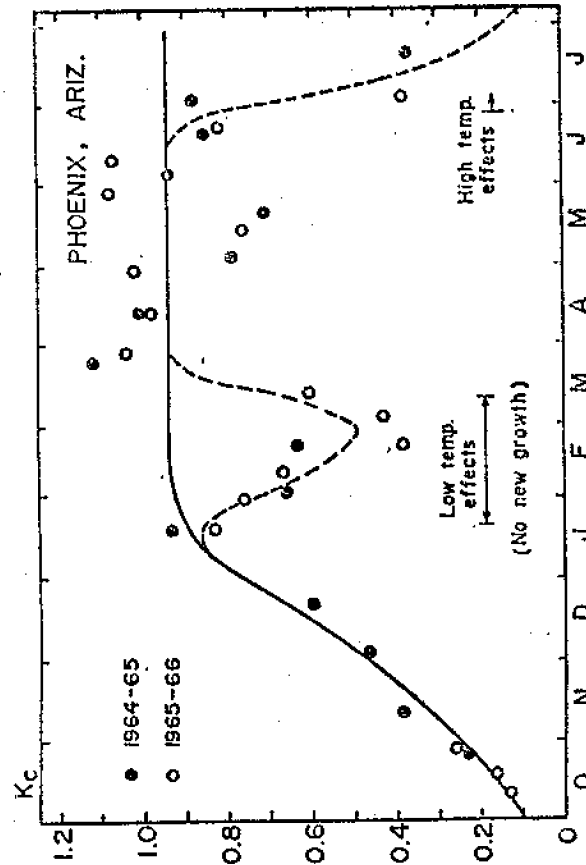


FIG. 8.10. Crop coefficients (E_t/E_o) for fall-planted sugarbeets at Phoenix, Arizona.

trates the effect of inactive leaves caused by low temperatures. The crop coefficient rapidly increases in March to an average of about 90 percent of the potential until near the end of June, then rapidly decreases because of limited leaf area. The solid line is plotted to illustrate what might be expected in slightly warmer climates where the leaves do not drop off during the winter months because of low minimum temperatures or during June and July because of high temperatures. In the Phoenix area, harvesting of sugarbeets begins in April because beets cannot be stored for processing. Irrigation of sugarbeets in that area on a silt loam soil could be terminated about one month before the anticipated harvest date without a reduction in sucrose (5).

PEAK RATES

From the data presented in the previous section, the average rates of evapotranspiration for spring-planted sugarbeets in the intermountain and Northern Plains area range from 0.22 to 0.26 inch per day during the latter part of July and the early part of August. Average rates of evapotranspiration range from 0.26 to 0.30 inch per day from early July to mid-August in the Columbia Basin area. In the Southern Plains, average rates range from 0.28 to 0.32 inch per day from early June to mid-August. These values also

would be applicable in the western Kansas area as indicated by the data presented by Herron et al. (13), shown in Figure 8.6. The values for Kansas were essentially the same as those for Bushland after the first of June. Average rates of evapotranspiration range from 0.30 to 0.35 inch per day in Arizona and southern California from mid-April to June. Pruitt et al. (30) measured a peak use rate of about 0.30 inch per day from mid-June to the latter part of July at Davis.

SEASONAL EVAPOTRANSPIRATION

Seasonal evapotranspiration for sugarbeets varies with the evapotranspiration rate for an area and the length of the growing season. Published values of seasonal evapotranspiration for sugarbeets from southern Alberta to Phoenix are summarized in Table 8.1. These data indicate that seasonal evapotranspiration ranges from about 22 inches in southern Alberta and the Northern Plains to about 40 inches in the Southern Plains for spring-planted sugarbeets, and about 42 inches for fall-planted sugarbeets in Arizona if allowed to grow until July. If fall-planted sugarbeets are harvested earlier, the seasonal evapotranspiration will be reduced accordingly.

ESTIMATING EVAPOTRANSPIRATION

Seasonal evapotranspiration can be estimated using a well-known procedure such as the Blaney-Criddle equation (1), or it can be estimated using Equation 8.3. The Blaney-Criddle formula for seasonal estimates is as follows:

$$U = KF = \sum k_f \quad (8.4)$$

where U = estimated evapotranspiration (consumptive use) in inches for the growing period or season; K = empirical consumptive use coefficient (irrigation season or growing period); F = the sum of monthly consumptive use factors, f , for the season or growing period ($f = tp/100$ where t = mean monthly air temperature, in degrees F, and p = mean monthly percent of annual daytime hours); and k = monthly consumptive use coefficient.

If Equation 8.3 is used, the average crop coefficient for the season will be approximately 0.75 or 75 percent of the potential evapotranspiration from planting to harvest. Monthly consumptive use coefficients for the Blaney-Criddle formula must be determined for each major area, or adjusted accordingly. For example, Erie et al. (6) summarized semimonthly coefficients for most crops grown in Arizona. These coefficients are based on average local planting to harvest periods. The Blaney-Criddle formula should not be used in climatic zones significantly different from those in western United States unless local coefficients are available.

TABLE 8.1. Summary of root and sugar yield and seasonal evapotranspiration

Source of Data	Location	Length of Season	Root Yield (tons/acre)	Sugar Yield (tons/acre)	ET (inches)
Ripley (31)	Tabor and Vauxhall, Alberta, Canada	1950-1961 Average	23.4	8.5	23.0
Larson and Johnston (22)	Huntley, Mont.	20 Apr.-27 Sept. 1953	22.0	—	22.5
Erie and Dimick (4)	Redfield, S. Dak.	1951 1952 1953	24.7 19.6 15.4	...	25.0 23.0 24.0
Jensen and Carter*	Twin Falls, Idaho	13 Apr.-21 Oct. 1963 23 Apr.-17 Oct. 1966 8 Apr.-12 Oct. 1967	22.9 25.5 24.7	4.0 4.4 3.6	24.0 23.0 26.0
Pruitt et al. (30)	Davis, Calif.	25 Mar.-21 Sept. 1966	29.0	3.3	33.5
Mech (25)	Prosser, Wash.	11 Mar.-26 Oct. 1949	36.4	5.9	37.0
Herron et al. (13)	Garden City, Kans.	4 Apr.-28 Oct. 1939	29.8	4.3	39.0
Schneider and Mathers (35)	Bushland, Tex.	15 Apr.-3 Nov. 1969 9 Apr.-22 Oct. 1964 16 Mar.-13 Oct. 1966	31.7 16.2 24.1	5.3 ...	31.0 40.0 38.0
Erie and French (5)	Phoenix, Ariz.	12 Oct. 1964-27 July 1965 22 Sept. 1965-7 July 1966	32.5 39.3	4.5 5.4	40.0 43.0

* Unpublished data.

If irrigations are to be scheduled using current meteorological conditions, estimates of evapotranspiration for periods as short as 5 to 10 days are required. These can be obtained using Equation 8.2 and a simple two-parameter approximate energy balance equation for estimating potential evapotranspiration:

$$E_p = C_T(T - T_a)R_a \quad (8.5)$$

where C_T is an air temperature coefficient which is constant for a given area and is derived from the long-term mean maximum and minimum temperatures for the month of highest mean air temperature, T is mean daily air temperature, T_a is a constant for a given area and is merely the linear equation intercept on the temperature axis, and R_a is daily solar radiation expressed as the equivalent depth of evaporation. However, potential evapotranspiration can be estimated more reliably if additional climatological data such as windspeed and mean daily dew point temperature are also used. An equation of this type is known as a combination equation, since it involves a combination of energy balance and aerodynamic terms. There are several forms of this equation. The one listed below is a modified Penman equation:

$$E_p = \frac{\Delta}{\Delta + \gamma} (R_a - G) + \frac{\gamma}{\Delta + \gamma} (15.36) (1.0 + 0.01W) (e_s - e_a) \quad (8.6)$$

where E_p is potential evapotranspiration in langleyes; Δ is the slope of the saturation vapor pressure-temperature curve, de/dT ; γ is the psychrometric constant; e_a is the mean saturation vapor pressure in millibars (mean at maximum and minimum daily air temperature); and e_s is the saturation vapor pressure at mean dew point temperature in millibars. The parameters $\Delta/(\Delta + \gamma)$ and $\gamma/(\Delta + \gamma)$ are mean air temperature weighting factors whose sum is 1.0, W is total daily wind run in miles, R_a is daily net radiation in cal cm⁻², and G is daily soil heat flux in cal cm⁻². Details on the use of these equations were presented by Jensen, Robb, and Franzoy (19). Where meteorological data are not available for an area, evaporation from a U.S. Weather Bureau pan can be substituted for the estimate of potential evapotranspiration if the pan is surrounded by an irrigated crop like grass.

MANAGING THE SOIL MOISTURE RESERVOIR

With irrigation, the grower can obtain excellent seed germination and stand establishment without depending on rain. A good stand is the first prerequisite for a good yield. Following stand establishment, irrigation enables the grower to regulate the soil moisture reservoir that is exploited by sugarbeet roots. Instruments such as soil moisture tensiometers and soil moisture blocks are available for directly or indirectly indicating the

soil moisture status. An experienced irrigator can assess the probable level of the soil moisture reservoir by taking samples of soil down to a depth of at least two feet and evaluating the soil moisture content by feel and visual appearance. There are certain basic concepts that are generally accepted for practical purposes in describing the soil moisture status. These are described in the following section.

SOILS AND THEIR WATER-HOLDING CAPACITIES

Soil moisture cannot be maintained at a constant level under normal irrigation practices. Instead, the soil is wetted by an irrigation, dries as the crop extracts water, and is rewetted by the next irrigation. Following an irrigation, if an adequate amount of water is applied, the soil moisture content is very high, but generally the soil is not saturated except at the surface. In a well-drained, fine-textured soil that has been thoroughly irrigated, the water slowly drains by gravity for as much as 60 days if evaporation is prevented. However, the drainage rate is very slow after 2 to 6 days. The moisture content at this stage is called "field capacity." The suction required to extract water at this time is only about 0.2 to 0.33 atmosphere (3 to 5 pounds per square inch). Plants can extract water from soils until the soil moisture tension approaches 15 atmospheres (about 225 pounds per square inch). This value is referred to as the "wilting point" or the wilting percentage. The water held by the soil between these values is called "available water."

The amount of water extracted does not increase uniformly as the soil moisture tension increases from 0.2 atmosphere to 15 atmospheres. Most of the water is extracted at lower suctions, especially on sandy soils. The percentage of water removed as the soil moisture tension increases to various values is presented in Table 8.2 for various soil types. The amount of available water that can be held by these soils ranges from about 0.8 inch in the loamy sands to as much as 2.5 inches per foot in the clays. The available water in medium-textured soils in which most of the sugarbeets are grown ranges from about 1.5 to 2 inches per foot.

TABLE 8.2. Approximate percentage of available water that can be depleted from soils by the time the soil moisture tension reaches the values indicated

Soil Moisture Tension (Atmospheres)	Percentage of Available Water Depleted in:			
	Loamy sand	Fine sandy loam	Sandy loam	Clay
0.5	70	65	57	30
1.0	82	75	63	27
2.0	89	83	72	57
5.0	95	92	89	73
10.0	99	98	97	87
				95

SOURCE: Adapted from Haise and Hagen (12).

IRRIGATION PRACTICES

During the past half century, there have been distinct changes in the recommendations of soil moisture levels to be maintained, the amounts of irrigation water to be applied, and the frequencies of irrigation. A summary of historical recommendations and more recent recommendations is presented in this section to illustrate these changes. To clarify some of the current conflicts in opinions, the recommendations are referenced to the time at which they were made.

Historical Guides to Irrigation. In 1899 Foster (9) made the following statement, which has apparently persisted with many sugarbeet growers even though later studies have shown this to be incorrect:

Never irrigate until beets show they require moisture, usually letting them suffer a few days, and by so doing it gives a nice long tapering root.

The following excerpt was taken from USDA Farmers' Bulletin No. 392, *Irrigation of Sugar Beets* (35):

It is essential that there be sufficient moisture in the soil at the time of seeding to bring the plants up, and it is better to irrigate before rather than after seeding. The next irrigation, or the first in the case it is not necessary to irrigate to bring the beets up, should be delayed as long as there is sufficient moisture in the soil to keep up a steady growth. Too early irrigation tends to make a turnip-shaped beet and produces an unusually heavy growth of leaves without a corresponding development of the root.

USDA Farmers' Bulletin No. 1645, *Sugar-Beet Growing Under Irrigation in the Utah-Idaho Area*, was released about 20 years later (28). The following excerpts illustrate some of the changes in the thinking during this period:

As a whole, growers in the irrigated areas put too much reliance on rainfall and fail to irrigate the beet crops sufficiently following planting and in the early stages of the crop. A forward step in sugar-beet growing in the irrigated area will be taken when the practice of prompt irrigation following planting is generally adopted.

... At one time there were popular opinions to the effect that irrigating the sugar beets early in the season prevented deep rooting, and that late irrigation reduced the sugar content of beets. It has been found that these opinions are not based upon facts. The beets should be irrigated whenever the leaves turn a dark-green color or begin to wilt in midday and do not quickly recover at night.

The beets should be irrigated late in the season, if necessary, to keep them in a growing condition. At digging time soil should be in a good friable ulth, since where the soil is very dry there is a loss of roots by breaking, and on the other hand, if the soil is wet, mud clings to the beets, thereby increasing the tare. There-

fore, the last irrigation should be timed so as to bring the land into good condition for harvesting.

These excerpts are from USDA Farmers' Bulletin No. 1867, *Sugar-Beet Culture Under Irrigation in the Northern Great Plains* (29):

Irrigation should begin whenever the soil is deficient in moisture. The normal rainfall of this area may provide sufficient moisture for germination of the seed; however, in many years irrigation is needed. . . . It is advisable to apply water within 24 hours after planting. If application of water is delayed, a portion of the seed may be in soil moist enough to sprout it; the rest may remain ungerminated. Uneven stands, because of such unevenness in germination of the seed, are very common where irrigation is delayed. . . .

When growing of sugar beets first began in the irrigated districts, it was commonly believed that irrigating early in the season would prevent the beet roots from growing deeply and would cause branching. This has not been found to be correct. Branching of the main root of sugar beets arises from a number of causes, such as high water table, loose seedbed, and insect or disease injuries. . . .

In the Nebraska district, it is commonly recognized that after irrigation is begun, a series of light irrigations, about 10 days apart, give better yields than less frequent and heavier individual applications. One of the most serious faults in irrigation practice is the tendency to delay the first application of water.

... The sugar beet obtains approximately 65% of its water from the top foot of soil and 85% of its moisture from the top two feet. The natural storage of water in the soil and deeper penetration of excess waters usually provide for sufficient moisture in the area below two feet. Keeping the top foot moist is the most important factor in irrigation of sugar beets. This requires more frequent but less heavy irrigations. If too much water is used the soluble plant foods are carried out of the soil or to depths where they are not readily recovered.

The following excerpt is from USDA Farmers' Bulletin No. 1903, *Sugar-Beet Culture in the Intermountain Area with Curly Top Resistant Varieties* (36):

Beets should be irrigated whenever the leaves turn dark green or begin to wilt in midday and do not recover at night. This is true whether the beets have only a few leaves or are nearing maturity. There are still many farmers who believe that withholding water early in the season until the small beets suffer "drives the roots down to water," and thus produces a larger beet. This theory has been disproved many times in field tests. Young beets must not be allowed to suffer for water.

More Recent Recommendations. These excerpts are from the 1955 USDA Yearbook of Agriculture, *The Irrigation of Sugar Beets* (11):

Because the length of the growing season is probably the first limitation on yield, the crop should be irrigated before the soil gets so dry as to delay plant growth. Any delay in the rate of growth is equivalent to shortening the growing season.

The beet plant is especially sensitive to unfavorable moisture conditions for three or four weeks after it emerges. During that time, the soil should be kept moist in the upper 12 inches, so that growth will be continuous and fast. If irrigation is necessary, then it should be light, so as to avoid leaching of soluble plant nutrients.

The quantity of available soil nitrogen is closely related to irrigation practice. The yield of beets may be seriously depressed by too much irrigation water and by too little water.

The following excerpts are from Chapter 33, Sugar, Oil, and Fiber Crops, Part 1, Sugar Beets (23):

Under field conditions, considerable attention has been given to whether irrigation should be withheld so that the crop will wilt immediately prior to harvest. Such practices are based in part on a common misconception that the resulting increase in sugar concentration represents a real increase in quality. . . . While preharvest wilting may offer savings in irrigation and hauling costs it usually increases harvest costs on soils with a high clay content, reduces storage and slicing quality through lower turgidity of the root, and sometimes reduces the extraction of sucrose. Total sucrose yields are not increased and may be reduced significantly by single, brief cycles, and almost invariably are lowered by repeated wilting due to reduction in leaf area and rate of photosynthesis. . . .

Both sprinkler or furrow irrigations are satisfactory with sugar beets while flood irrigation may contribute to pathogen problems (fungal root rot) and is not suitable. Sprinklers provide the best control of water distribution, prevent surface isolation of nutrients, and, on coarse textured soils, conserve water and reduce leaching of nutrients. The choice between sprinkler and furrow irrigation is an economic one dependent on the relative costs and advantages of the systems under conditions prevailing in a given situation.

The following excerpt is from Water Management of Fall-Planted Sugar Beets in Salt River Valley of Arizona (5):

Water management during the first six weeks is especially important from the standpoint of water conservation and early growth. It is during this period that leaching, germination, weed control, stand maintenance, fertilizer and thinning are accomplished. The plant's moisture needs are very low during this period, so any individual application of water greater than two inches, except for leaching, is probably wasted. . . . Sugar beets will use moisture from deep profiles. However, nearly 90% of the water used is from the top three feet of soil. . . . Sugar beets can extract water from a depth as great as five feet, but over 70% of use is from the top two feet of soil.

Summary of Changes in Irrigation Recommendations. The general concept of withholding irrigations until the plants suffer in order to obtain a long tapering root (9, 33), apparently initiated during the late 1800s, persisted for nearly a half century even though many experiments did not verify this theory. Later, many of the researchers stressed the need for early light irri-

gations to assure germination and establishment of good stands. This is still good advice today and has become a standard recommendation (23).

Many of the researchers stressed the need to irrigate when the beets do not recover from midday wilting at night. They also began to recommend the maintenance of soil moisture late in the season, but this seemed to be primarily for harvesting and processing purposes.

Irrigations at intervals of 10 to 14 days were recommended in the intermountain areas and the Northern Great Plains, with the last irrigation about September 15. This is a valid recommendation except that the interval may be increased after mid-August.

Most researchers stressed the fact that roots may penetrate to 5 or 6 feet. Doneen's data (9), for example, show more complete water extraction to greater depths than Haddock (11) found in Utah. This observation has been repeated extensively, but must be qualified because on some soils the rooting depth may be restricted by cemented material or dense silt and clay layers.

The statement by Nuckols that "very fertile soils require somewhat less water per pound of crop produced as compared with soils of low fertility" is valid, but should not be construed to mean less total water is needed.

EFFECTS OF SOIL MOISTURE LEVELS ON YIELDS

The results of irrigation experiments involving various levels of soil moisture depletion before irrigating are summarized in Tables 8.3 to 8.8. These experiments were conducted at Huntley, Montana; Newton and Garland, Utah; Prosser, Washington; Davis, California; Twin Falls, Idaho; and Phoenix, Arizona. The most significant aspect of these experiments is that the production of sugarbeet roots is generally not very sensitive to soil moisture stress. For example, in each of these studies, reducing the total number of irrigations about 35 percent by allowing greater depletion of soil moisture before irrigating reduced the root yield only about 5 to 8 percent. However, the amount of water applied per irrigation usually

TABLE 8.3. Summary of irrigation regimes and root and sugar yields in 1953 at Huntley, Montana

Irrigation Regime*	Number of Irrigations	Root Yield	Gross Sugar	
			Yield	(tons/acre)
High	8	23.4		5.46
Medium	5	22.0		3.08
Low	1	16.9		2.45

SOURCE: Larson and Johnston (22).

NOTES: Planted 20 Apr. and harvested 27 Sept. Soil type: Fly Creek clay loam; 12 tons of manure and 90 lb N and 54 lb P₂O₅ per acre.

* Approximate percentage of available water removed from the root zone was 36, 75, and 95 percent for the wet, medium, and dry treatments before irrigating, respectively.

TABLE 8.4. Summary of irrigation regimes and root yields at Newton, Utah, in 1946 and at Garland, Utah, in 1947

Irrigation Regime†	1946*		1947†	
	Number of irrigations	Root yield (tons/acre)	Number of irrigations	Root yield (tons/acre)
W ₁	6	24.9	8	27.5
W ₂	4	...	5	28.7
W ₃	3	21.9	4	24.9
W ₄	2	19.8	3	22.5

SOURCE: Haddock (10).

NOTE: Planted 22 Apr. 1946 and 12 Apr. 1947. Harvested 24 Oct. 1946 and 10 Oct. 1947. Soil type = Millville fine sandy loam at Newton and Millville silt loam at Garland.

* With 160 lb N and 15 tons manure per acre.

† With 80 lb N and 15 tons manure per acre.

‡ W₁ = continuously moist, below 0.75 atmosphere at the 8-inch depth in 1946 and the 6-inch depth in 1947.

W₂ = similar to W₁ to 12 Aug. 1946 and 28 July 1947.

W₃ = similar to W₁ to 15 July 1946 and 26 June 1947, then soil moisture was allowed to reach the wilting percentage at 18 inches before irrigating.

W₄ = similar to W₁ to 15 July 1946 and 26 June 1947, then soil moisture was allowed to reach the wilting percentage at 30 inches in 1946 and at 36 inches in 1947 before irrigating.

was to be greater with less frequent irrigations since less frequent irrigation has only a small effect on total evapotranspiration.

Salter and Goode (34) in their review of crop responses to water at different stages of growth summarized studies in England and indicated that soil moisture deficit in midseason may be more important than those occurring in mid-September. They also reviewed recommendations made by individuals as early as 1892 that irrigations late in the season may raise the yield of roots in England but may not result in an increased yield of sugar. However, they also cited data from Canada, reported over a 9-year

TABLE 8.5. Summary of irrigation regimes and root and sugar yields at Prosser, Washington, in 1948

Irrigation Regime*	1946*		1947†	
	Number of irrigations	Root yield (tons/acre)	Number of irrigations	Root yield (tons/acre)
Wet	12	36.9	8	36.4
Medium	8	36.4	6	33.6
Dry	6	33.6	5.5	5.5

SOURCE: Meek (25).

NOTE: Planted 11 Mar. and harvested 26 Oct. Soil type: Warden fine sandy loam. * Irrigation water was applied when the average available water in the 4-foot profile was 60 percent, 35 percent, and 15 percent for the wet, medium, and dry treatments, respectively. Since the soil held about 2.3 inches of available water per foot, the amount of water extracted amounted to about 3.7 inches, 6.0 inches, and 7.8 inches for the wet, medium, and dry treatments, respectively.

TABLE 8.6. Summary of irrigation regimes and root and sugar yields at Davis, California, in 1961

Irrigation Regime*	1946*		1947†	
	Number of irrigations	Root yield (tons/acre)	Number of irrigations	Root yield (tons/acre)
Wet	13	31.6	8	31.6
Medium	8	29.8	5	28.1
Dry	5	26.4	3	26.4
Dry + stress	3	26.4	3	26.4

SOURCE: Loomis and Haddock (23). Unpublished data of L. D. Doneen and R. S. Loomis. The crop was planted at Davis, Calif., 14 May 1961 (late) on a deep, well-drained, Yolo loam. Means in the table represent four replications of two harvest dates, 14 Sept. and 27 Oct., and two nitrogen levels.

* Wet = irrigated every 5 to 6 days after cover was nearly complete.

† Medium = between the wet and dry.

Dry = irrigated at the first sign of wilting.

Dry + stress = allowed to wilt about three days before irrigation.

TABLE 8.7. Summary of irrigation regimes and root and sugar yields at Twin Falls, Idaho, from 1964 through 1967

Irrigation Regime*	1964		1965†		1966		1967	
	Year	Number of irrigations	Year	Number of irrigations	Year	Number of irrigations	Year	Number of irrigations
M-H-1	1964	11	1965†	13	1966	10	1967	10
M-H-2	1964	11	1965†	13	1966	10	1967	10
M-1	1964	7	1965†	9	1966	10	1967	10
M-2	1964	7	1965†	9	1966	10	1967	10

NOTE: Planting and harvest dates:

Year	Planted	Harvested
1964	19 Apr.	22 Oct.
1965	13 Apr.	22 Oct.
1966	26 Apr. (replanted)	17 Oct.
1967	8 Apr.	12 Oct.

Soil type = Portneuf silt loam, lime-silica cemented layer beginning at 16-18 inches restricts root development.

* M-H-1 = irrigated 12 hours when the soil moisture tension at 8 inches approached 0.6 atmosphere.

M-H-2 = same as M-H-1 except irrigation was applied 24 hours.

M-1 = irrigated 12 hours when the soil moisture tension at 8 inches approached 4 atmospheres.

M-2 = same as M-1 except irrigation was applied for 24 hours.

† For a nitrogen treatment of 100 lb/acre.

‡ Second year on the same plots.

TABLE 8.8. Summary of irrigation regimes and root and sugar yields at Phoenix, Arizona, in 1964-65 and 1965-66

Irrigation Regime*	Year	Number of Irrigations	Root Yield† (tons/acre)	Gross Sugar Yield (tons/acre)
Wet	1965-65	14	31.6	3.89
	1965-66	12	37.8	4.99
Medium	1964-65	11	32.5	4.14
	1965-66	10	39.3	5.38
Dry	1964-65	8	32.9	4.47
	1965-66	7	38.8	5.08

SOURCE: Erie and French (5).

NOTE: Planted 12 Oct. 1964 and 22 Sept. 1965. Harvested 27 July 1965 and 7 July 1966.

Soil type = Cajon silt loam, 130 lb nitrogen applied.

* Irrigation regimes initiated 23 Apr. 1965 and Mar. 1966. Irrigated when 40 percent, 60 percent, and 80 percent of the water was depleted on the wet, medium, and dry treatments, respectively. These correspond to depletions of about 2, 3, and 4 inches, respectively, for the three regimes.

† Yields will be less with earlier harvest dates.

period, that no decrease in sugar content of roots resulted from continuing to irrigate until late in the season. Salter and Goode concluded:

From the experimental work cited there are no obvious indications that this crop, when grown for its roots, is especially sensitive to soil moisture conditions at any particular stage of growth, although few workers have critically studied this particular aspect of its water relations. The conflicting evidence for and against early and late irrigation can probably be explained by the overriding effect of variable soil and weather conditions, including temperature, which prevail during the different experiments.

ALLOWABLE DEPLETION AND IRRIGATION INTERVALS

Based on the results presented in the two previous sections, it is apparent that sugarbeets can be irrigated at a high soil moisture level with frequent, light irrigations, or they can be allowed to deplete 60 to 70 percent of the available water in the root zone between irrigations if each irrigation refills the amount depleted. The interval between irrigations cannot be estimated on a basis of evapotranspiration values alone (Fig. 8.3 to 8.9). Instead, the available water-holding capacity per foot of depth and the expected depth of rooting for the soil in question must be known. Rainfall, of course, can also influence irrigation frequency. The general recommendation for an irrigation frequency from July 14 to the latter part of August of 10 to 14 days now appears to be very reliable for near-maximum yields. As a general rule, if one assumes that 60 percent of the available water in the root zone can be depleted and uses the average evapotranspiration rates presented in Figures 8.3 to 8.8, then the desired irrigation interval can be obtained during periods when rainfall is not significant.

cant. However, with some sprinkler systems, the frequency of irrigation will be determined by the amount of soil moisture replenished at each irrigation and the evapotranspiration rate essentially independent of available water-holding capacities.

Greater depletion can be allowed near the end of the season if moist soil is not needed for harvesting the beet roots. Ferry, Hills, and Loomis (7) conducted a study in 1963 in the San Joaquin Valley where beets are harvested in July and August. Their results indicated that moisture stress before harvest decreased root yields but increased the sucrose percentage, and therefore, only slightly decreased the gross sugar production. Erie and French (5) found that late season soil moisture stress decreased root weight but increased the sugar percentage to compensate for the loss in root weight. They concluded that since sucrose is not reduced by soil moisture stress, irrigations can be discontinued 3 to 4 weeks before harvest for maximum water economy.

SOIL MOISTURE-NITROGEN INTERACTIONS

In general, if adequate soil moisture is provided so as not to restrict growth, uptake of available soil nitrogen does not appear to be restricted. Excessive water application will reduce yields where the nitrogen level is just adequate, that is, for comparable yields, more nitrogen fertilizer is required if excessive water is applied (32). At Twin Falls, Idaho, for example, the 4-year average yields were 22.7 and 23.2 tons per acre with about 50 and 100 lb of nitrogen, respectively, with 12-hour irrigation sets. With 24-hour sets the average yields were 21.4 and 22.5 tons per acre for 50 and 100 lb of nitrogen per acre, and 23.1 tons per acre for 200 lb of nitrogen per acre.

IRRIGATION WATER REQUIREMENTS AND METHODS

Irrigation water requirements will be greater than the evapotranspiration values shown in the previous section because there are unavoidable losses. With the present methods of irrigating, for example, the desired quantity of water cannot be applied uniformly over the entire field. Also, where leaching is required to control salts, additional water must be added if this is not met by the excess water applied under normal irrigation practices.

A schematic diagram is presented in Figure 8.11 to illustrate the major reason for irrigation water requirements being greater than evapotranspiration for surface irrigation systems and in Figure 8.12 for sprinkler irrigation systems. In Figure 8.11, if water is applied until an adequate amount is absorbed at the lower end of the field and the water reaches the end of the field in about one-third of the total time, the water application efficiency will be about 65 percent. Although this will vary with soils of different intake characteristics, this example illustrates that approximately 50 per-

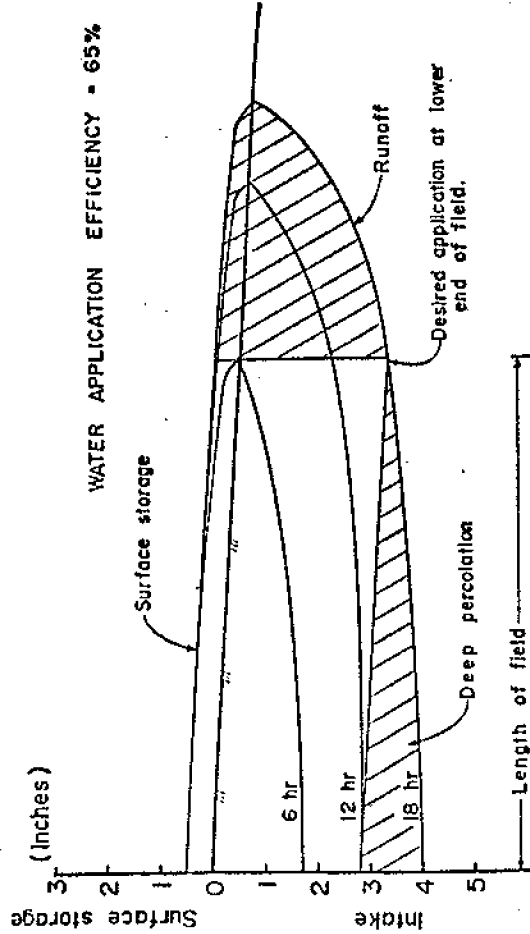


FIG. 8.11. If water is applied to furrows until an adequate amount is absorbed at the lower end of the field, the water application efficiency may be only 65%.

cent more water may be applied to a sloping field with furrow irrigation than that amount merely needed to replenish the depleted soil moisture.

Estimates of the advance of water in furrows for other soils and stream sizes can be made using the following equation:

$$x = \frac{qt}{0.8D_s + 0.67I_s} \quad (8.7)$$

where x = the distance to the advancing front (ft), q = the average flow rate per foot of width ($\text{ft}^3/\text{ft-hr}$), D_s = the average depth of water on the surface at the upper end of the field per foot of width (ft), I_s = the depth of water infiltrated at the upper end at time t (ft), and t = time in hours.

A typical example of the distribution of water from a sprinkler system for a single irrigation and the cumulative distribution after four irrigations is presented in Figure 8.12. To assure adequate water applied throughout the area for a single irrigation, a water application efficiency of about 77 percent would be needed. If one assumes that the evaporative loss during sprinkling will be about 7 percent, then a water application efficiency of 70 percent would be required to apply the desired amount of water to all areas. The improvement in water application efficiency after consecutive irrigations is the result of changes in wind direction and velocity from one irrigation to the next.

Because the evapotranspiration process concentrates the salts in the

Percent of average

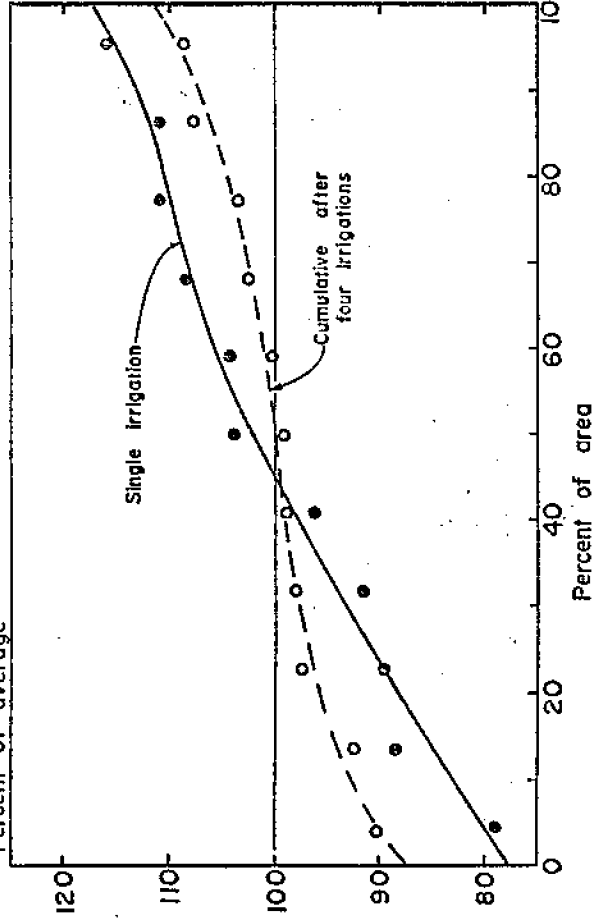


FIG. 8.12. Distribution of water from a typical sprinkler system for a single irrigation and after four irrigations. (Unpublished data from C. H. Pair.)

water applied to the soil, these salts must be removed by leaching. The quantity of water required for leaching is proportional to the weighted average concentration of soluble salts in the applied water, C_{aw} , the volume of water used by evapotranspiration, W_{ev} , and inversely proportional to the concentration of salts that can be tolerated in the root zone, C_r . The salt concentration in the soil solution between irrigations increases as the plants extract water, but for convenience consider C_r = the average salt concentration of water in the root zone when the soil is near field capacity. Where rainfall is negligible, the salt concentration in the applied water (rainfall + irrigation water) is essentially the same as in the irrigation water, C_{ir} .

The volume of water required for leaching, W_L , under steady-state conditions, or long periods of time, can be estimated as follows:

$$W_L = \frac{C_{aw}}{a(C_r - C_{aw})} W_{ev} \quad (8.8)$$

In this equation, a = the leaching efficiency expressed as a fraction. The leaching efficiency is a coefficient expressing the ratio of the average salt concentration in the drain water to the average concentration of the soil water in the root zone at a soil moisture content near field capacity as stated in the following equation:

$$a = \frac{C_{ar}}{C_r} \quad (8.9)$$

C_{ar} is the concentration of soluble salts in the drainage water. The ratio, C_{ar}/C_{dr} is the same as the "leaching requirement" when the salt concentration in the irrigation water is taken as the weighted average of rain-water and irrigation water. The concentration given in Equation 8.8 and 8.9 can be replaced by the electrical conductivity, EC, of the water.

A more complete description of the leaching requirement, its limitations and the significance of the assumptions involved, can be found in USDA Handbook 60, published by the U.S. Salinity Laboratory Staff (38), and in a bulletin by Wilcox (39).

In the intermountain and Northern Plains areas, sugarbeets are either flat planted or planted on shallow beds with a furrow spacing of 22 inches, as illustrated in the upper portion of Figure 8.13. Water is usually applied in alternate furrows, at least for the first few irrigations. Typical wetting patterns from the furrows are shown. The second general procedure for irrigating, and this is probably used more frequently in areas where saline conditions exist, is to have wider beds and deeper furrows with two sugarbeet rows approximately 12 inches apart on each bed. When water is applied in the furrow, typical wetting patterns as illustrated occur and the

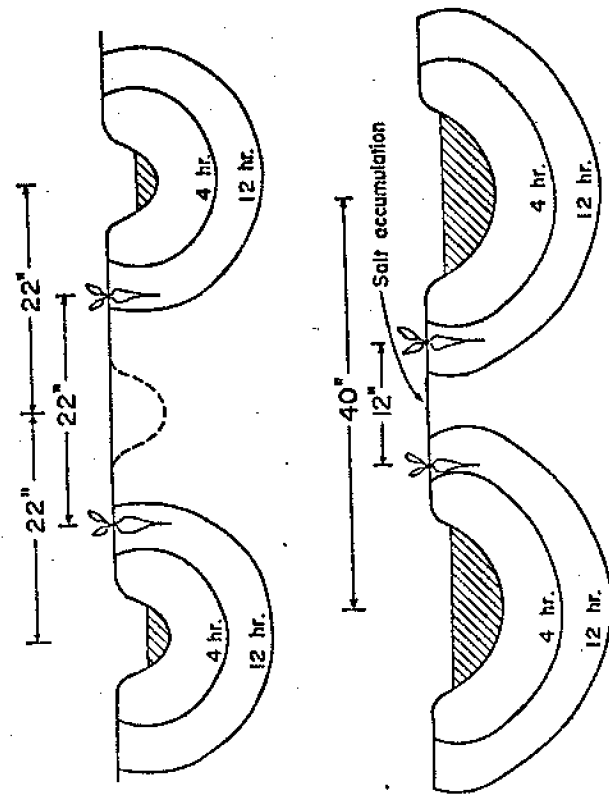


FIG. 8.13. Typical flat-planted, shallow furrows and bed-planted, deep furrows and expected wetting patterns.

salts tend to accumulate between the two rows and thereby result in better soil conditions for the germination and emergence of the seedlings. One other advantage of the large beds and the deep furrows in areas where land slopes are very small is that these systems can be installed perfectly level and no runoff occurs. Water must be applied to the deep furrows rapidly to move the water to the end of the field, and then must be reduced to maintain the depth of water close to the surface of the ridge to wet the soil for germination. When using this technique and nearly filling the furrow, one can apply a light irrigation of about 2½ inches. If water is kept in the furrow, additional amounts can be applied.

Although border strips have been used for sugarbeet irrigation, they are not common. One of the problems encountered with the irrigation of sugarbeets in border strips is the large change in the retardance of the flow as the sugarbeet leaves develop. A summary of the increased depth of flow in the borders and the retardance in the rate of advance of water in a border is presented by Jensen and Howe (18). These data indicate that the time required for water to reach the end of the border strip may increase as much as 1½ to 2 times as a result of additional retardance created by the sugarbeet leaves.

PREPLANTING AND PREEMERGENCE IRRIGATIONS

Preplanting and preemergence irrigations are usually applied to wet the subsoil and to wet the surface soil for germination and emergence. Water is usually kept in the furrow until it subs to the row. Irrigation for emergence may not be required in areas where frequent light precipitation occurs during the time of planting. Generally, very light irrigations are required for germination purposes, but these are difficult to apply with surface systems.

EARLY-SEASON IRRIGATIONS

An irrigation is usually needed after thinning and/or after side-dressing of nitrogen fertilizer. Thinning often delays a normal irrigation, resulting in low soil moisture in the seedling zone. Also, disturbed seedlings recover more rapidly if irrigated. An irrigation will move soluble fertilizers into the root zone of the seedlings. The movement of soluble materials is perpendicular to the wetting front illustrated in Figure 8.13. Therefore, nitrogen fertilizer should be applied to the side and just below the shallow furrows and to the side and about even with the bottom of deep furrows. If side-dressing is applied immediately below the furrow, a significant portion of the soluble material may be leached out of the root zone. Frequent, light irrigations may be required in high wind areas like the Texas High Plains to protect the seedling against wind damage.

MIDSEASON IRRIGATIONS

Midseason irrigations are largely for replenishing the soil moisture depleted by evapotranspiration plus leaching if necessary. Since most of the depletion takes place in the upper two feet of soil, these irrigations should apply sufficient water to refill the upper two feet to field capacity. If no leaching is needed, the frequency of the surface irrigations will depend on the rate of evapotranspiration during this period, rainfall, and the available water-holding characteristics of the soil. The net amount of water applied during midseason irrigations will probably vary between three and four inches on most soils and between four and five inches on deep soils. The number of irrigations needed can be approximated by dividing total evapotranspiration by the amount to be applied per irrigation where rainfall is negligible. In the Northern Plains where rainfall may partially replenish the depleted soil moisture, the irrigation interval may be more variable from one year to the next. With sprinkler systems, the frequency may depend on the amount applied per set.

LATE-SEASON IRRIGATIONS

In the northern areas and in the intermountain areas, the evapotranspiration rate is generally only about 0.15 inch per day late in the season. The time of the last irrigation before harvest depends on the soil moisture condition desired at harvest. If moist soil is desired, then an irrigation 10 days to two weeks before harvest is preferred. In Arizona and on deep soils where water may be expensive, the last irrigation can be applied three to four weeks before harvest if moist soil is not needed for harvesting. If an irrigation is applied close to harvest, then only a light amount should be applied.

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